# THE EFFECT OF URBAN DEVELOPMENT ON PEAK WATER FLOW, BOWLING GREEN, OHIO: 1950–1969[1]

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*Abstract.* An attempt is made to analyze land use changes and resultant increases in peak water flow in an urbanizing area. The study compares land use, infiltration, and peak water flow for a 16 mile$^2$ area centered on Bowling Green, Ohio, for 1950, before accelerated urban development, with the same area for 1969, after development. Peak water flow increases attributed to urban development on former agricultural land, and the resultant problems of drainage and excess water, are of specific concern. In the study area, a combination of near-level topography, clay-rich soils, and paved commercial areas produce a peak water flow greater than the capacity of storm drainage ditches. Storm drainage facilities are not adequate to handle the increased peak water flow caused by urban development demonstrating the need for proper land use planning prior to urban development.

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Changes in the environment in and around cities can be attributed in large part to population concentration and urban growth. The process of urban growth disturbs the natural environment—the greater the urbanization, the greater the disturbance. One such disturbance appears to be the increase in peak water flow and the decrease in infiltration as cities and suburbs spread, covering the land surface with pavement, commercial buildings, multiple dwelling units, and factories (U.S. Dept. of the Interior 1971). Relatively few studies have attempted a detailed analysis of land use changes over time and the resultant increases in peak water flow in an urbanizing area.

It has been shown that water imposes constraints on land use not easily reconciled through basic flood control measures (Spieker 1970). Either flood control measures must be improved or land use must be restricted where significant changes in peak water flow occur with land development. Unfortunately, urban development combined with improved drainage systems has the effect of reducing lagtime of water movement downstream. Increased storm runoff increases the flood peaks downstream by a factor of 2 to 8, depending on the degree of urban development (Anderson 1970). Areas chosen for development should contain soils where infiltration rates are high enough to prevent pronounced increases in runoff.

The comparison of an area before and after urbanization has yielded some insights into the effects of development. Indications are that the direct runoff after urban development can be 1.1 to 4.6 times greater than the corresponding runoff during the pre-urban period (Seaburn 1969). Various time spans have been utilized in such comparison studies, but a 20 year time period seems adequate for measuring the expected changes.

Several studies have examined land use relative to hydrologic conditions (Institute for Environmental Studies 1968; Hammer 1971). The results have shown that in order to minimize the undesirable effects of urbanization on stream hydrology, restrictions on further urban development would be necessary near any stream. Despite such comprehensive attempts, a need remains for investigations of peak flow, infiltration, and precipitation patterns in specific urban settings. Improvements in and adaptations of

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available technology may enable us to treat urban drainage problems more efficiently.

A number of studies treat the engineering aspects of peak rates of discharge in relation to storm drainage facilities, but few deal with the problem of urbanization and peak water flow in a comparative spatial context (King 1967). One major difficulty has been the lack of readily available quantitative data on rainfall-runoff relationships. A standardized formula devised by the Soil Conservation Service showed that a simulated model can accurately substitute for actual rainfall and runoff data (Smith 1970). Our study attempts to determine the effects of urban development on the infiltration and peak water flow for a 16 square mile area centered on Bowling Green, Ohio. A comparison is made of peak flow and infiltration data between 1950, before accelerated urban development, and 1969, after urban development. Working under the assumption that peak water flow is increased and that infiltration is decreased as land use changes and as an urban area expands, we attempted to assess the factors which influence peak flow in an urban environment and to determine the immediate consequences of an increased concentration of water with respect to land use and storm drainage facilities.

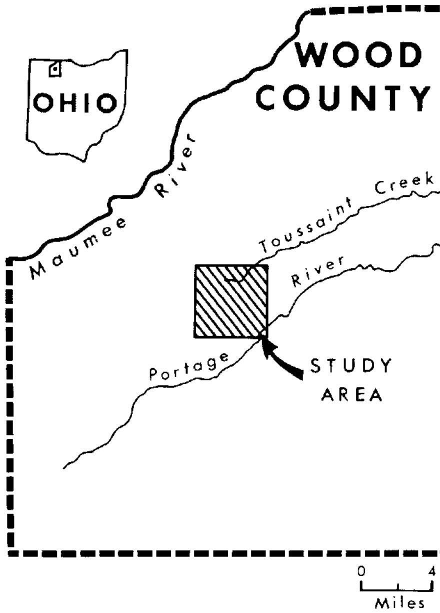


FIGURE 1. Location of study area.

## STUDY AREA

The area chosen for this study is located in northwestern Ohio in a glacial lake plain once occupied by the "Black Swamp", a product of various lake stages during the Wisconsin Glacial Age (Kaatz 1955). The area consists of level expanses of impermeable clay-rich soils interspersed with sand ridges (Rapparle and Urban 1966) and is centered on the city of Bowling Green which occupies a site within the watersheds of the Maumee River, the North Branch of the Portage River, and the Toussaint Creek (fig. 1). The study area was selected because Bowling Green is the largest of the communities in the former swamp.

The Bowling Green area was covered by a series of relatively shallow ice-marginal lakes during the late Wisconsin period. Clays and silts settled to the bottom of these calm water bodies creating a clay-rich deposit one to eight feet thick (Forsyth 1968). The deposition of fine particles added to the underlying clay loam or clay glacial till in creating a very impermeable surface material. Overlying the clay-rich glacial till, and the water-deposited and water-sorted materials, are a number of elongated, relatively narrow sand ridges. The ridges represent materials deposited by waves in the proglacial lakes as shorelines, offshore bars, or islands. As lake levels lowered, the Bowling Green area emerged as the ice front melted and the glaciers retreated northward. The lacustrine and glacial materials weathered at the surface to develop the soils of the area. Because of the broad, flat, clay-rich plain, the area suffered from very poor drainage. The flatness of the land and the impermeable clays were major causes in the formation of the Black Swamp (Forsyth 1966), and contribute to present drainage problems.

The Bowling Green area seems to be plagued by water problems related to drainage facilities. The open ditches, originally constructed by the early German settlers, are ineffective in times of peak water flow. Seasonal flooding occurs on the farms around the city and costly water damage has been incurred by many residents within the city. The soils still present an almost impervious barrier to large amounts of precipitation. Over 50% of the study area is situated on soils of the Hoytville association. These soils have a very slow infiltration rate when thoroughly wetted and generally have a nearly impervious clay-rich horizon at shallow depth.

## METHODS

A 16 square mile study area was selected to include all of the major urban developments in and around the city of Bowling Green, Ohio plus an area of rural land outside of the city limits. Having both urban and rural portions included in the study area allowed for comparisons of

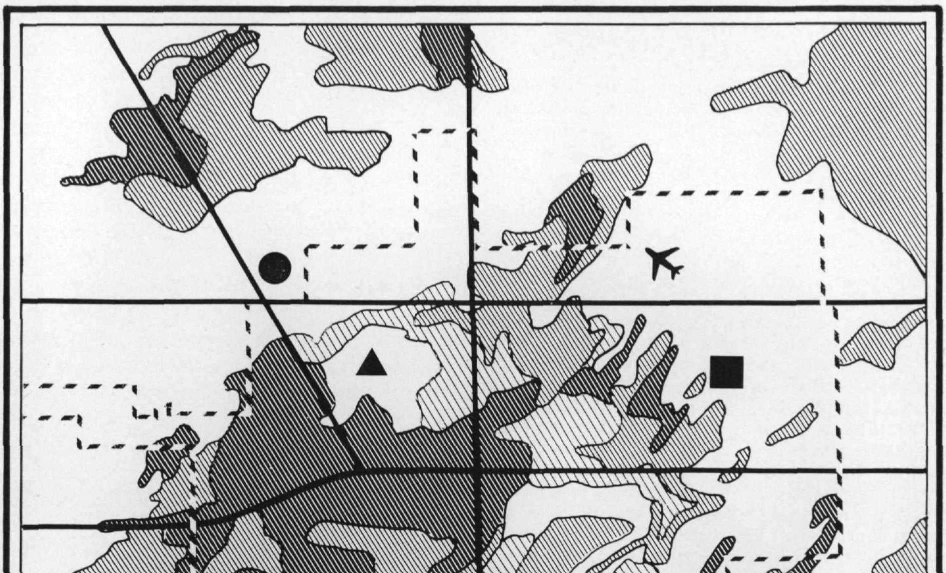


FIGURE 2. Generalized hydrologic soil groups of the Bowling Green area. See footnote table 1 for a description of hydrologic soil groups A, B, C, D.

relationships of infiltration and peak water flow to different natural and man-made environments.

The soils of the study area were placed into four general hydrologic groups based on infiltration rates (fig. 2). The group of soils with high infiltration includes the Dunbridge, Ottokee, and Spinks series. The group of soils with moderate infiltration includes the Colwood, Mermill, Millsdale, and Wauseon series. The group of soils with slow infiltration includes the Haskins, Digby, and Milton series. The group of soils with very slow infiltration includes the Hoytville, Nappanee, and Randolph series. The clustering of soils made it easier to calculate infiltration rates, runoff, cover conditions, and related soil features.

A standard formula (devised by the Soil Conservation Service) was utilized to calculate peak water flow (Kent 1971). The formula uses accumulated volume of runoff based on accumulated rainfall, surface storage of moisture, interception by vegetation, and infiltration prior to runoff to determine water flow and assumes a static relationship between the initial calculation of surface storage, interception by vegetation, and infiltration, and the potential maximum retention of water by soil. An average antecedent moisture condition during the growing season was also assumed. Peak water flow calculations were based on a probability storm of one year frequency 24 hour rainfall, which is approximately 2.2 inches for the study area (Kent 1971).

A grid network was used to divide the study area into 256 sections of 40 acres each. The sections were further subdivided whenever necessary and categorized into one of 12 urban or rural land use groups (table 1), using aerial photographs. The aerial photographs were used to determine the differences in land use between 1950 and 1969. The precentage of change in land use in each of the 12 categories over the 20 year period was calculated and compared to the percent change in peak flow from 1950 to 1969. Causes and immediate consequences of the increased volume of water then were assessed by examining residential subdivisions and commercial developments in the Bowling Green area.

## RESULTS AND DISCUSSION

### LAND USE CHANGES

Between 1950 and 1969 the population of Bowling Green increased from about 12,000 (U.S. Bureau of the Census 1952) to over 21,000 (U.S. Bureau of the Census, 1971). The region was transformed from a compact town into a spreading city. Bowling Green University expanded to accommodate an increasing number of students, and the functions of the commercial districts grew to meet the needs of the increased population. Shopping centers were constructed on the east and south edges of the city. Apartment complexes were developed on previously rural land and annexation of rural land for industrial development added another segment to the urban use categories by 1969 (fig. 3).

In 1950 the urban land use categories encompassed about 11% of the study area and covered only the central por-

TABLE 1

*Percentage change in land use in and near Bowling Green, Ohio: 1950–1969.*

| Category | Land Use | Hydrologic Soil Group Infiltration rate | | | |
|---|---|---|---|---|---|
| | | Rapid A† | Moderate B† | Slow C† | Very Slow D† |
| I | Wood or Forest | −0.1 | −0.3 | −0.1 | −0.2 |
| II | Pasture | −0.4 | −0.8 | −0.2 | −0.9 |
| III | Row Crops | +0.1 | −0.3 | +0.1 | −1.9 |
| IV | Grain Crops | −1.5 | −2.8 | −0.9 | −8.5 |
| V | Lawns, Parks, Cemeteries | +0.2 | −0.2 | −0.1 | +1.4 |
| VI | Paved Commercial Areas | +0.4 | +2.2 | +0.6 | +5.2 |
| VII | Row Houses and Apartments | +0.2 | +0.9 | +0.3 | +0.6 |
| VIII | Residential, Lot Size of ½ acre | +1.0 | +0.4 | +0.4 | +0.7 |
| IX | Residential, Lot Size of 1 acre | +0.1 | +0.6 | −0.1 | +0.4 |
| X | Residential, Lot Size of 2 acres | +0.1 | +0.1 | +0.1 | +0.4 |
| XI | Newly Graded Commercial Area | +0.1 | +0.1 | −0.1 | +0.2 |
| XII | Newly Graded, Residential Area | +0.1 | +0.1 | +0.1 | +0.3 |

†A = 5 or more inches/hour.
B = 0.2 to 5.0 inches/hour.
C = 0.05 to 0.2 inches/hour.
D = 0.05 or less inches/hour.

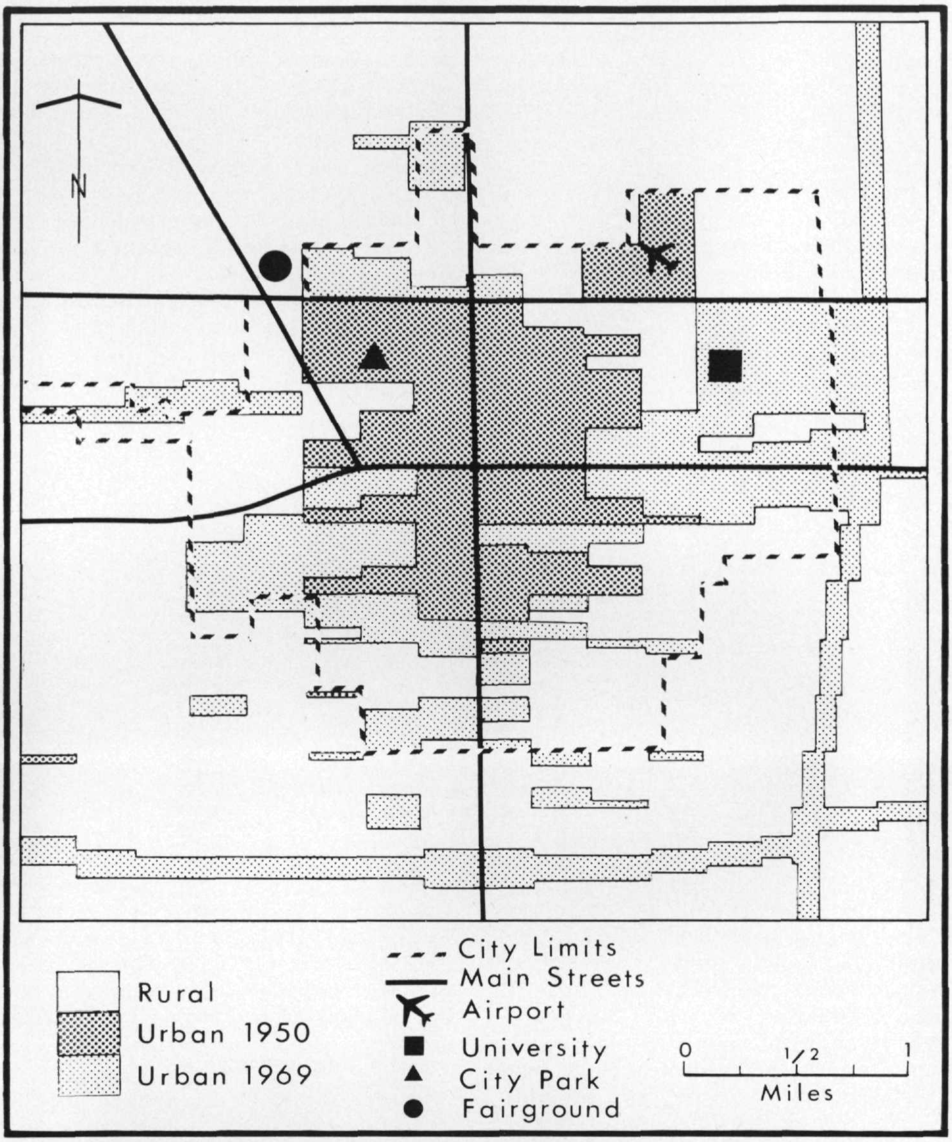


FIGURE 3. Land use comparisons for the Bowling Green area: 1950/1969.

tion of the area. By 1969 the urban land uses had increased in size to include about 28% of the area; almost a threefold increase in urban use space. Large urban tracts were annexed on University property in the northeast sector of the study area west of a newly developed Interstate highway. Residential subdivisions were included in the southwest and northwest sectors of the area. The most conspicuous additions were a 4 lane Interstate highway (No. 75) east of the city and the 4 lane U.S. highway (No. 6) bypass south of the city. The addition of urban land amounted to about 17% of the study area (table 1).

The 4 rural land use categories lost acreage to urban uses between 1950 and 1969. Woodlots (category I) had a loss of 85 acres (0.6%) to urban uses for the study period. Pasture land (category II) lost 73 acres (0.5%) to urban uses but had a gain in acres on poorly drained clay soils. The acreage lost from row crops (category III) totaled 763 acres (2.1%) of the study area. The acreage previously in grain crops (category IV) was affected most by changes over the time period. Almost 1312 acres (14%) of the study area were converted to urban land uses from grain crop acreage. From 1950 to 1969, 2232 acres of rural land were transformed into one of the eight urban land use categories (table 2).

TABLE 2

*Acres lost to, or gained by, urban land use categories: 1950–1969.*

| Category | Land Use | Acres Lost or Gained |
|---|---|---|
| I | Wood or Forest | − 85.00 |
| II | Pasture | − 72.75 |
| III | Row Crops | − 762.50 |
| IV | Grain Crops | −1311.38 |
| V | Lawns, Parks, Cemeteries | + 121.88 |
| VI | Paved Commercial Areas | + 845.10 |
| VII | Row Houses and Apartments | + 195.13 |
| VIII | Residential, Lot Size of ½ Acre | + 245.00 |
| IX | Residential, Lot Size of 1 Acre | + 136.88 |
| X | Residential, Lot Size of 2 Acres | + 62.75 |
| XI | Newly Graded, Commercial Area | + 50.00 |
| XII | Newly Graded, Residential Area | + 49.90 |

All of the 8 urban land use categories had a net gain in acres from 1950 to 1969. Category V (lawns, parks, cemeteries) had an increase (122 acres) because of the land annexed by the University. Paved commercial areas (category VI) had the largest increase of acreage over the time period. Over 8% of the study area was changed to pavement during this time period (table 1). The largest contributing factor for this change were the additions of the Interstate Highway and the U.S. Highway by-pass. An area of approximately 845 acres was paved during the 20 year period.

The high density residential sectors (category VII) had a net increase of 195 acres; almost 2% of the study area was transformed to apartment complexes. Residential sectors with ½ acre lots (category VIII) had an increase of 254 acres (2.5%) for the study area. One acre residential lots (category IX) had an increase of 137 acres (1.5%) for the study area. Most of this increase was on well drained sandy soils. Land use category X (residential lots of two acres) had a small net gain of 63 acres. Most of this increase was on the poorly drained Hoytville clays.

Newly graded commercial areas (category XI) registered an increase of 50 acres. New commercial developments located in the southern sector on poorly drained soils contributed the largest proportion of the gain. Newly graded residential regions with no vegetation established (category XII) had a net gain of about 50 acres during the time period. This development was on poorly drained soils of the Hoytville association.

## PEAK WATER FLOW

Wide variations in permeability, and hence in peak water flow, were calculated for the study area. Rainfall and runoff depths were obtained from runoff charts for selected land use categories. Figures for peak water flow relative to infiltration (hydrologic soil group) were calculated for the one year frequency storm based on the SCS standard formula for runoff (table 3). This method proved to be flexible enough to incorporate the peak water flow rates for the soil types and land uses of the study area. The data were accurate except for the need to interpolate the peak water flow for parks

TABLE 3

*Peak flow rates for different soil groups for a 2.2 inch 24 hour rainfall.*

| Land Use Category | Rapid† A | Moderate B | Slow C | Very Slow D |
|---|---|---|---|---|
| I | 0.00 | 0.21 | 0.56 | 0.83 |
| II | 0.26* | 0.64 | 1.00 | 1.19 |
| III | 0.38 | 0.73 | 1.12 | 1.34 |
| IV | 0.19 | 0.51 | 0.89 | 1.12 |
| V | 0.00 | 0.11 | 0.45 | 0.68 |
| VI | 1.98 | 1.98 | 1.98 | 1.98 |
| VII | 0.68 | 0.95 | 1.27 | 1.68 |
| VIII | 0.00 | 0.32 | 0.68 | 0.95 |
| IX | 0.10 | 0.26 | 0.64 | 0.89 |
| X | 0.00 | 0.21 | 0.56 | 0.73 |
| XI | 0.73 | 1.19 | 1.50 | 1.68 |
| XII | 0.73 | 1.19 | 1.32 | 1.58 |

*Rate in inches.
†See table 1 for footnote on A, B, C and D.

and woodlots on sandy soils because the values for these land uses were below the chart minimum.

In the developed sectors the peak water flow from the paved surfaces was generally greater on an equal area basis than the flow from the permeable surfaces. The highest rates of peak water flow in the study area occurred during and after intense rainfalls. The soil type and kind of vegetation growing had a major effect on the precipitation that resulted in peak water flow (Chorley 1971). And a factor of 0% to 3% slope contributed to the peak water flow rates of the region. Most of the water was removed from the surface so slowly that the water table was near the surface in the depressed sites after an intense rainfall (Hunt 1972). In most areas the near-level topography helped to increase infiltration and thereby reduce the peak water flow.

From 1950 to 1969 the total peak discharge rate for the study area increased from 1812 cubic feet per second (cfs) to 2232 cubic feet per second for a 2.2 inch 24 hour one year frequency rainfall. These figures were obtained by adding the total peak discharge rates for the twelve land use categories for 1950 (1812 cfs) and for 1969 (2232 cfs). The rural land use categories registered a net decrease in total peak discharge rate, and the urban categories registered a net increase. The total peak discharge rate for the rural categories was 202 cfs less in 1969 than in 1950 and rate for the urban land use categories increased by 630 cfs during the study period (fig. 4).

The increases in the total peak discharge rate for the urban land use categories more than compensated for the decreases in the rate from the rural sectors. An increase in total acreage for lawns, parks and cemeteries (V) led to an increased total peak discharge rate of 14 cfs. The most important increase in peak discharge was 350 cfs for paved commercial areas (VI) (fig. 4), because of the sizeable increase in land occupied by shopping centers.

All of residential land use categories showed a net increase in the total peak discharge rate over the time period. Row houses and apartments (VII), constructed on previously rural land to accomodate the increased population of Bowling Green, showed an increase of 114 cfs. Residential lots of one-half acre (VIII) registered a net increase of 30 cfs in the peak discharge rate. The larger home sites of category IX showed a discharge rate increase of 16 cfs. The 2 acre residences (X) had an increase of only 10 cfs because new residential developments of this type were generally on well drained soils and the resultant total peak discharge rate remained low.

High increases in the total peak discharge rate were determined for the newly

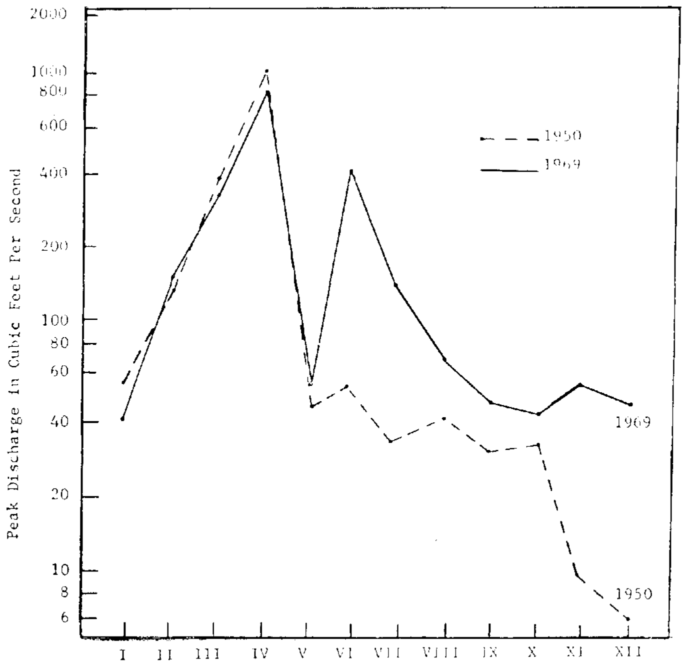


FIGURE 4. Total peak discharge comparisons: 1950/1969.

graded sectors of land use categories XI and XII. The near absence of these land uses in 1950 and the increased construction of 1969 accounted for the increase in the total peak discharge rate. Category XI (newly graded commercial) showed a net increase of 47 cfs whereas category XII (newly graded residential), which was absent in 1950, showed an increase of 46 cfs.

## DRAINAGE AND SEWAGE FACILITIES

During the study period from 1950 to 1969 there was very little improvement of storm drainage facilities in the Bowling Green area. Where new commercial and residential areas developed there was an addition of storm drainage units, but these units did not adequately control the peak water flow during and immediately after storm situations (Hill 1963). To further complicate the problem, many sewers carried storm water as well as sanitary effluent. This placed much of the burden of the problem of storm drainage on sewage treatment facilities. The problem could be alleviated somewhat by separating storm drainage facilities from sewage treatment facilities, but, a more complete network of storm drains and better storm drain outlets seem to be needed.

The Bowling Green sewage treatment plant was designed to treat a maximum of 4.76 million gallons of effluent in 24 hours. The average daily amount treated in 1969 ranged from 5 to 6 million gallons in a 24 hour period. A one inch 24 hour rainfall produced a peak water flow of more than 40 million gallons. Part of the peak water flow was removed by storm drainage ditches, but much of the peak water flow was channeled through the sewage treatment plant and eventually into the adjacent open drainage ditch. This amount of peak water flow, expected each year, overtaxed the sewage treatment facilities by more than 35 millions gallons. Thus, both storm and sanitary drainage have entered the adjacent drainage ditch on several occasions. The untreated sanitary drainage entering the system has been responsible for fishkills in the Portage River downstream.

## CONCLUSIONS

About 17% of the land in the study area was transformed into an urban function. As a result of the land use changes, the effective area available for infiltration decreased considerably from 1950 to 1969. Large tracts of paved commercial areas and apartment complexes reduced the infiltration capacity for more than 1000 acres. The 2 four-lane highways crossing the study area reduced the infiltration capacity of this previously rural land. Large parking facilities on Bowling Green State University land also lowered the infiltration capacity.

The altered and impervious surfaces increased the total peak discharge rate from about 1800 cfs in 1950 to more than 2200 cfs in 1969 and increased the average soil moisture content for the locations adjacent to the paved land use categories. The increased soil moisture contributed to a longer period of soil saturation during each year. A saturated soil condition generally produced a higher total peak discharge rate.

Increased urban development outpaced the development of storm drainage facilities and increase in peak water flow, caused by the land use changes, produced an overload for three of the four storm drainage networks serving the study area causing hardships for the residents. Tax money had to be used to repair water-damaged streets. Flooded basements occurred in areas with bedrock outcrops and nearly impervious clay soils and lawns and driveways were damaged by water overflowing from storm drains. The peak water flow problem has not yet reached the stage where costs of damage have reached the projected cost level for developing a more adequate drainage system. However, the water flow problem must be approached on a scale that adequately deals with the entire Bowling Green area rather than with particular site improvements or changes for each development.

The better drained soils of the study area have been developed already and the sandy soils of hydrologic group "A" have been covered by ½ to 2 acre residential lots. Improvements to the storm drainage network do not appear to be needed for these areas as long as the land use remains residential because peak water flow for these residential areas is low. If the land is transformed into paved commercial areas, a more complete storm drainage network could be necessary because the peak water flow for commercial area is much higher than the peak water flow for residential areas.

The poorly drained clay soils of the Hoytville soil association (Hydrologic group "D") are the only large tracts of land that are not yet completely developed and commercial and residential development on these less desirable soils appears to be imminent. Commercial centers are already planned north and south of the city on these clay-rich soils. These paved shopping centers will cover large tracts of previously rural land and peak water flow is expected to more than double while infiltration is expected to be reduced considerably. These commercial tracts will need the addition of vegetation to help induce infiltration into the soil. The drainage system developed for the commercial centers should be designed to ensure that the peak water flow is controlled so that nearby residential areas will not receive the flow from the newly constructed paved areas. Most of the recent development in the eastern sector of the study area has been on the poorly drained clay soils and any further development in this sector would be on Hoytville soils. Most of the undeveloped land owned by the University also is on poorly drained soils. High amounts of peak water flow can be expected to occur at these sites in the future if more development occurs (U.S. Dept. of Agriculture 1968). The existing open storm drains in the area will not be able to control the additional amount of peak water flow from a 2.2 inch 24 hour one year frequency probable rainfall.

If adequate drains are not installed in conjunction with the urban development, the residents of the area can look forward to greater flooding problems in the future, such as pavement cracked by standing water, frequently flooded basements, interrupted movement of traffic, and damaged lawns, gardens, and crops adjacent to paved areas. Any new construction needs an addition to and renovation of present storm drainage facilities.

Our study indicates that careful planning of land use and proper distribution of storm drains did not precede development in the Bowling Green area. It also indicates the need for planning in other locations. Data compiled in determining peak flow rates support empirical evidence that urban development must be curtailed if there is inadequate provision of storm sewers and other storm drainage facilities to handle the projected increase in peak water flow. The application of the SCS standard formula technique is useful for planners in identifying locations where development would interfere least with natural infiltration capacities. Soils with higher infiltration rates such as those in Group A in the study area can be developed with little or no change in runoff. Soils with very low infiltration rates such as those in Group D should have development greatly restricted. Thus, once the porous soils have been developed, no further development should occur in a given area.

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